

PHOTOPOLYMERIZABLE COMPOSITIONS THAT INCLUDE ALICYCLIC/AROMATIC
DIOXIRANES AND NOVEL DIOXIRANYL TETRAOXASPIRO [5.5] UNDECANES

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

Not Applicable.

CROSS-REFERENCE TO RELATED APPLICATIONS

Not Applicable.

FIELD OF THE INVENTION

[0001] This invention relates in general to compositions of matter and, more particularly, to compositions that include an expanding monomer, which may be one of the novel dioxiranyl tetraoxaspiro[5.5]undecanes (TOSU) disclosed herein, and a dioxirane. These compositions may also include a polyol, a photoinitiator, a photosensitizer and/or a reaction promoter. The polymerizable compositions of the present invention are useful for a variety of applications, including use as dental materials, such as composites.

BACKGROUND OF THE INVENTION

[0002] Many types of monomers undergo shrinkage during polymerization to a degree that makes them generally unsuited for use in numerous applications, including for use as stress-free composites, high-strength adhesives, and precision castings. As an example, when such monomers are used in composites which contain inorganic fillers, the polymeric matrix is subject to failure when the polymer shrinks and pulls away from the filler particles. Failure of the composite can also occur when the matrix ruptures as a result of voids or micro cracks which form in the matrix during polymerization shrinkage.

[0003] Polymeric matrices commonly employed in dental materials such as adhesives and composites are based on 2,2'-bis[4-(2-hydroxy-3-methacryloyloxypropoxy)]phenyl propane

(BisGMA). A significant problem associated with the use of this monomer in dental applications is the shrinkage which occurs as the monomer is polymerized. The BisGMA monomer itself typically experiences high shrinkage, and when a low viscosity reactive diluent is combined with the monomer, the shrinkage may even be higher. The adverse effects of such shrinkage are believed to include increased postoperative sensitivity, the formation of marginal gaps between the dental restoration and the cavity wall, cracking of the restoration, and microleakage and potential failure of the restoration.

[0004] The discovery that spiroorthocarbonates may undergo reduced polymerization contraction and possibly polymerization expansion has led to the suggestion of their use in reinforced composites, including as dental materials. Spiroorthocarbonates are esters of orthocarboxylic acid and have four oxygen atoms bonded to a single carbon atom, with the carbon atom being common to two ring systems. The expansion of the spiroorthocarbonates on polymerization is attributed to a double spiro-cyclic ring opening of the spiroorthocarbonates, resulting in the breaking of two covalent bonds to form one new bond.

[0005] Initial attempts to form a homogeneous polymer matrix from certain spiroorthocarbonates and BisGMA resin mixtures proved unsuccessful because of the incomplete polymerization of the spiroorthocarbonates. Thompson et al., J. Dental Research 58:1522-1532 (1979). More recent studies demonstrated that homogeneous mixtures of other spiroorthocarbonates and BisGMA could be obtained. Stansbury, J. Dental Research 70:527; Abstract No. 2088 (1991).

[0006] The photocationic-initiated expansion polymerization of alicyclic spiroorthocarbonate monomers and the potential use of the resulting polymers in dental materials have been previously reported by some of the present inventors, with others. Byerley et al., Dent. Mater. 8:345-350

(1992). The specific spiroorthocarbonates identified by Byerley et al. include cis/cis, cis/trans, and trans/trans configurational isomers of 2,3,8,9-di(tetramethylene)-1,5,7,11-tetraoxaspiro[5.5]undecane. These spiroorthocarbonates were determined to undergo an expansion of 3.5% during homopolymerization and demonstrated acceptable cytotoxicity and genotoxicity properties, making them promising components of composite resin matrix materials.

[0007] Some of the present inventors, with others, have also previously reported on the preparation of a copolymer of an alicyclic spiroorthocarbonate and an unidentified monofunctional epoxide, with the observation that there were no indications of the formation of small ring compounds as polymerization by-products. Byerley et al., J. Dental Research 69:263; Abstract No. 1233 (1990). The copolymerization of trans/trans-2,3,8,9-di(tetramethylene)-1,5,7,11-tetraoxaspiro[5.5]undecane and commercially available multifunctional epoxides was also disclosed in a paper presented by Byerley et al., Abstract No. 1233, cited above. However, no physical or mechanical properties, including percentage shrinkage, of the copolymer compositions were disclosed. Still further, spiroorthocarbonate copolymers have been created that are capable of yielding a hard, non-shrinking matrix resin. These copolymers include a trans/trans-2,3,8,9-di(tetramethylene)-1,5,7,11-tetraoxaspiro[5.5]undecane spiroorthocarbonate, a polymerizable epoxy resin, and a hydroxyl containing material, as described in U.S. Patent No. 5,808,108.

[0008] A diepoxy spiroorthocarbonate, namely, 3,23-dioxatrispiro[tricyclo[3.2.1.0<2,4>]octane-6,5'-1,3-dioxane-2'2"-1,3-dioxane-5",7'"-tricyclo[3.2.1.0<2,4>octane], is disclosed in a book entitled, "Expanding Monomers, Synthesis, Characterization and Applications," edited by R. J. Sadhir and R. M. Luck, CRC Press, Boca Raton (1992), pp. 329-332.

[0009] Some of the present inventors, with others, have previously disclosed the spiro-orthocarbonates 2,8-dimethyl-1,5,7,11-tetraoxaspiro[5,5]undecane and 3,9-diethyl-3,9-dipropionyloxymethyl-1,5,7,11-tetraoxaspiro[5,5]undecane in an article entitled "Photoreactivity of Expanding Monomers and Epoxy-Based Matrix Resin Systems" by Chappelow et al., J. of Applied Polymer Science, Vol 76, 1715-1724 (2000).

[0010] However, none of the above disclosed spiro-orthocarbonates used in a photopolymerizable composition generally exhibit characteristics desirable in a dental restorative, including flexible linkages, enhanced miscibility and reactivity and reduced photopolymerization contraction stress.

[0011] Despite the advances resulting from the above-noted polymeric compositions and SOC's, a need still exists for cationically photopolymerizable compositions exhibiting properties such as reduced shrinkage and reduced photopolymerization contraction stress. Still further, there is a need for expanding monomers containing flexible linkages that provide enhanced miscibility and reactivity in photopolymerizable compositions.

SUMMARY OF THE INVENTION

[0012] A visible light cationically photopolymerizable composition is provided. This composition includes an expanding monomer and a dioxirane. More specifically, the expanding monomer used in this composition is one or more dioxiranyl tetraoxaspiro[5.5]undecanes. The composition of the present invention may be used as a matrix resin for dental restorative materials. Still further, as another embodiment of the present invention, various novel dioxiranyl tetraoxaspiro[5.5]undecanes are provided.

[0013] Additional aspects of the invention, together with the advantages and novel features appurtenant thereto, will be set forth in part in the description which follows, and in part will become apparent to those skilled in the art upon examination of the following, or may be learned from the practice of the invention. The objects and advantages of the invention may be realized and attained by means of the instrumentalities and combinations particularly pointed out in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] In the accompanying drawings, which form a part of the specification and are to be read in conjunction therewith:

[0015] Fig. 1 is the structural formula of 3, 9-bis(cyclohex-3-enylmethyl)-1,5,7,11-tetraoxaspiro[5,5]undecane;

[0016] Fig. 2 is the structural formula of 3,9-bis[(7-oxabicyclo[4.1.0]hept-3-yl)methyl]-1,5,7,11-tetraoxaspiro[5.5]undecane;

[0017] Fig. 3 is the structural formula of 3, 9-bis[(6-methylcyclohex-3-enyl)methyl]-1,5,7,11-tetraoxaspiro[5,5]undecane;

[0018] Fig. 4 is the structural formula of 3, 9-bis[(4-methyl-7-oxabicyclo[4.1.0]hept-3-yl)methyl]-1,5,7,11-tetraoxaspiro[5,5]undecane;

[0019] Fig. 5 is the structural formula of 3, 9-bis(cyclohex-3-enylmethoxy)-1,5,7,11-tetraoxaspiro[5,5]undecane;

[0020] Fig. 6 is the structural formula of 3,9-bis[(7-oxabicyclo[4.1.0]hept-3-yl)methoxy]-1,5,7,11-tetraoxaspiro[5.5]undecane;

[0021] Fig. 7 is the structural formula of 3, 9-bis[(6-methylcyclohex-3-enyl)methoxy]-1,5,7,11-tetraoxaspiro[5,5]undecane;

- [0034] Fig. 20 is the structural formula of bis(3,4-epoxycyclohexylmethylenoxy)adipate;
- [0035] Fig. 21 is the structural formula of butanediol diglycidyl ether;
- [0036] Fig. 22 is the structural formula of polytetrahydrofuran;
- [0037] Fig. 23 is the structural formula of 2-oxepanone, polymer with 2-ethyl-2-(hydroxymethyl)-1,3-propane diol;
- [0038] Fig. 24 is the structural formula of (4-n-octyloxyphenyl)phenyliodonium hexafluoroantimonate;
- [0039] Fig. 25 is the structural formula of [4-(2-hydroxytetradecyloxyphenyl)]phenyliodonium hexafluoroantimonate;
- [0040] Fig. 26 is the structural formula of [4-(1-methylethyl)phenyl](4-methylphenyl)iodonium tetrakis(pentafluorophenyl)borate(1-);
- [0041] Fig. 27 is the structural formula of camphorquinone;
- [0042] Fig. 28 is the structural formula of 2-chlorothioxanthen-9-one;
- [0043] Fig. 29 is the structural formula of ethyl 4-dimethylaminobenzoate;
- [0044] Fig. 30 is the structural formula of 4,4'-bis(diethylamino)benzophenone;
- [0045] Fig. 31 is the synthesis scheme of 3, 9-bis(cyclohex-3-enylmethyl)-1,5,7,11-tetraoxaspiro[5,5]undecane and 3,9-bis[(7-oxabicyclo[4.1.0]hept-3-yl)methyl]-1,5,7,11-tetraoxaspiro[5,5]undecane;
- [0046] Fig. 32 is the ¹H-NMR spectrum of 3, 9-bis(cyclohex-3-enylmethyl)-1,5,7,11-tetraoxaspiro[5,5]undecane;
- [0047] Fig. 33 is the ¹C-NMR spectrum of 3, 9-bis(cyclohex-3-enylmethyl)-1,5,7,11-tetraoxaspiro[5,5]undecane;

[0048] Fig. 34 is the FTIR spectrum of 3,9-bis[(3'-cyclohexenyl)methyl]-1,5,7,11-tetraoxaspiro[5,5]undecane;

[0049] Fig. 35 is the ¹H-NMR spectrum of 3, 9-bis(cyclohex-3-enylmethyl)-1,5,7,11-tetraoxaspiro[5,5]undecane;

[0050] Fig. 36 is the ¹C-NMR spectrum of 3,9-bis(cyclohex-3-enylmethyl)-1,5,7,11-tetraoxaspiro[5,5]undecane;

[0051] Fig. 37 is the FTIR spectrum of 3,9-bis(cyclohex-3-enylmethyl)-1,5,7,11-tetraoxaspiro[5,5]undecane;

[0052] Fig. 38 is the synthesis scheme of 3, 9-bis[(6-methylcyclohex-3-enyl)methyl]-1,5,7,11-tetraoxaspiro[5,5]undecane and 3, 9-bis[(4-methyl-7-oxabicyclo[4.1.0]hept-3-yl)methyl]-1,5,7,11-tetraoxaspiro[5,5]undecane;

[0053] Fig. 39 is the ¹H-NMR spectrum of 3, 9-bis[(6-methylcyclohex-3-enyl)methyl]-1,5,7,11-tetraoxaspiro[5,5]undecane;

[0054] Fig. 40 is the ¹C-NMR spectrum of 3, 9-bis[(6-methylcyclohex-3-enyl)methyl]-1,5,7,11-tetraoxaspiro[5,5]undecane;

[0055] Fig. 41 is the FTIR spectrum of 3, 9-bis[(6-methylcyclohex-3-enyl)methyl]-1,5,7,11-tetraoxaspiro[5,5]undecane;

[0056] Fig. 42 is the ¹H-NMR spectrum of 3, 9-bis[(4-methyl-7-oxabicyclo[4.1.0]hept-3-yl)methyl]-1,5,7,11-tetraoxaspiro[5,5]undecane;

[0057] Fig. 43 is the FTIR spectrum of 3, 9-bis[(4-methyl-7-oxabicyclo[4.1.0]hept-3-yl)methyl]-1,5,7,11-tetraoxaspiro[5,5]undecane;

[0058] Fig. 44 is the synthesis scheme of 3, 9-bis[(6-methylcyclohex-3-enyl)methoxy]-1,5,7,11-tetraoxaspiro[5,5]undecane and 3, 9-bis[(4-methyl-7-oxabicyclo[4.1.0]hept-3-yl)methoxy]-1,5,7,11-tetraoxaspiro[5,5]undecane;

[0059] Fig. 45 is the ¹H-NMR spectrum of 3, 9-bis[(6-methylcyclohex-3-enyl)methoxy]-1,5,7,11-tetraoxaspiro[5,5]undecane;

[0060] Fig. 46 is the ¹C-NMR spectrum of 3, 9-bis[(6-methylcyclohex-3-enyl)methoxy]-1,5,7,11-tetraoxaspiro[5,5]undecane;

[0061] Fig. 47 is the FTIR spectrum of 3, 9-bis[(6-methylcyclohex-3-enyl)methoxy]-1,5,7,11-tetraoxaspiro[5,5]undecane;

[0062] Fig. 48 is the ¹H-NMR spectrum of 3, 9-bis[(4-methyl-7-oxabicyclo[4.1.0]hept-3-yl)methoxy]-1,5,7,11-tetraoxaspiro[5,5]undecane;

[0063] Fig. 49 is the ¹C-NMR spectrum of 3, 9-bis[(4-methyl-7-oxabicyclo[4.1.0]hept-3-yl)methoxy]-1,5,7,11-tetraoxaspiro[5,5]undecane; and

[0064] Fig. 50 is the FTIR spectrum of 3, 9-bis[(4-methyl-7-oxabicyclo[4.1.0]hept-3-yl)methoxy]-1,5,7,11-tetraoxaspiro[5,5]undecane.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0065] The present invention relates to photopolymerizable oxirane/1,5,7,11 tetraoxaspiro [5.5] undecane based compositions containing functional components. These compositions can be used as dental matrix resins. More specifically, the composition of the present invention includes a dioxirane (DO) and a dioxiranyl tetraoxaspiro[5.5] undecane, which can undergo polymerization

with reduced shrinkage. The latter component may also be referred to as an expanding monomer. The specific type of expanding monomers utilized in the composition of the present invention may be classified as 1,5,7,11-tetraoxaspiro[5.5] undecane (TOSU) derivatives. By using a dioxiranyl TOSU, the composition has the potential of reducing the amount of polymerization shrinkage of the total formulation.

[0066] The formulation further may include a polyol (PL) and/or a reaction promoter (RP). The reaction promoter is capable of accelerating the photopolymerization rate of the formulation. When proportionally formulated, homogeneous reaction mixtures of the present invention are capable of rapidly undergoing photoinitiated polymerization with less volume shrinkage and yielding polymerization with less stress than the corresponding dioxirane/polyol mixtures that do not contain a dioxiranyl TOSU monomer. In addition, the dioxirane/dioxiranyl TOSU/polyol resins of the present invention have the potential of forming chemical bonds with substrates containing multifunctional groups.

[0067] Still further, the formulation of the present invention may include a photoinitiator (PI) and/or a photosensitizer (PS). The polyol, reaction promoter and photosensitizer are optional components, and none, one, some or all of these components may be present in the formulation. These optional components may be used to create dental matrices with particular desired properties. Preferably the composition is cationically polymerizable by visible light. Preferably, the compositions of the subject invention are matrix resins for dental restorative materials. The two main classes of photopolymerizable compositions within the scope of this invention are identified as DO/TOSU mixtures and DO/TOSU/PL mixtures.

[0068] Examples of novel TOSUs that may be used in the composition of the present invention include, but are not limited to, 3,9-sis(cyclohex-3-enylmethyl)-1,5,7,11-tetraoxaspiro[5.5]undecane (BCHEM), 3,9-bis[(7-oxabicyclo[4.1.0]hept-3-yl)methyl]-1,5,7,11-tetraoxaspiro[5.5]undecane (BOCHM), 3,9-bis[(6-methylcyclohex-3-enyl)methyl]-1,5,7,11-tetraoxaspiro[5.5]undecane (BMCHEM), 3,9-bis[(4-methyl-7-oxabicyclo[4.1.0]hept-3-yl)methyl]-1,5,7,11-tetraoxaspiro[5.5]undecane (BMOCHM), 3,9-bis(cyclohex-3-enylmethoxy)-1,5,7,11-tetraoxaspiro[5.5]undecane (BCHEMO), 3,9-bis[(7-oxabicyclo[4.1.0]hept-3-yl)methoxy]-1,5,7,11-tetraoxaspiro[5.5]undecane (BOCHMO), 3,9-bis[2-methyl-7-oxabicyclo[4.1.0]hept-3-yl)methoxy]-1,5,7,11-tetraoxaspiro[5.5]undecane (BMCHEMO), 3,9-bis[(4-methyl-7-oxabicyclo[4.1.0]hept-3-yl)methoxy]-1,5,7,11-tetraoxaspiro[5.5]undecane (BMOCHMO), 3,9-bis(cyclohex-3-enyloxymethyl)-1,5,7,11-tetraoxaspiro{5.5}undecane (BCHEOM), 3,9-bis[7-oxabicyclo[4.1.0]hept-3-yl]oxymethyl]-1,5,7,11-tetraoxaspiro[5.5]undecane (BOCHOM), 3,9-bis[(6-methylcyclohex-3-enyl)oxymethyl]-1,5,7,11-tetraoxaspiro[5.5]undecane (BMCHEOM), and 3,9-bis[(4-methyl-7-oxabicyclo[4.1.0]hept-3-yl)oxymethyl]-1,5,7,11-tetraoxaspiro[5.5]undecane (BMOCHOM), 8,10,19,20-tetraoxatrispiro[5.2.2.5.2.2]henicosane-2,14-diene (TOTSHC), 7,26-dioxatrispiro[bicyclo[4.1.0]heptane-3,5'-1,3-dioxane-2'2''-1,3-dioxane-5'',4'''-bicyclo[4.1.0]heptane] (DOTSHH), and combinations thereof. These novel TOSUs are shown in FIGS. 1-16.

[0069] The dioxirane may be alicyclic and/or aromatic. Examples of dioxiranes (DOs) include, but are not limited to, diglycidyl ether bisphenol A, which may be obtained from Ciba Geigy under the trade name GY6004 or Shell under the trade name EPON 825; 3',4'-epoxycyclohexanemethyl-3,4-epoxycyclohexane carboxylate, which may be obtained from Union

Carbide under the tradename UVR 6105; bis(2,3-oxiranylcyclopentyl)ether (BOCPE), which may be obtained from Aldrich as number 45,567-9; butanediol diglycidyl ether, which may be obtained from Ciba-Geigy under the tradename RD 2; and bis(3,4-epoxycyclohexylmethyl) adipate, which may be obtained from Union Carbide under the tradename ERL-4299. Diglycidyl ether bisphenol A is shown in FIG. 17, 3',4'-epoxycyclohexanemethyl-3,4-epoxycyclohexane carboxylate is shown in FIG. 18, bis(2,3-oxiranylcyclopentyl)ether (BOCPE) is shown in FIG. 19, butanediol diglycidyl ether is shown in FIG. 20, and bis(3,4-epoxycyclohexylmethyl) adipate is shown in FIG. 21.

[0070] Examples of polyols (PLs) that may be used in the composition of the present invention include, but are not limited to, poly(tetrahydrofuran) (PTHF), average M=ca. 250, which may be obtained from Aldrich as number 34,526-1; 2-oxepanone polymer with 2-ethyl-2-(hydroxymethyl)-1,3-propane diol which may be obtained from Union Carbide under the tradename Tone 301; and combinations thereof. poly(tetrahydrofuran) (PTHF) is shown in FIG. 22, and 2-oxepanone polymer with 2-ethyl-2-(hydroxymethyl)-1,3-propane diol is shown in FIG. 23.

[0071] A diaryliodonium salt may be the photoinitiator. Examples of other photoinitiators (PIs) that may be used in the composition of the present invention include, but are not limited to, (4-n-octyloxyphenyl)phenyliodonium hexafluoroantimonate (OPIA), which may be obtained from GE Silicones under number 479-2092C; [4-(2-hydroxytetradecyloxyphenyl)]phenyliodonium hexafluoroantimonate (CD 1012), which may be obtained from Sartomer under the tradename SarCat CD-1012 or from Gelest under the tradename OMAN072; [4-1-methylethyl]phenyl](4-methylphenyl)iodonium tetrakis(pentafluorophenyl)borate(1-) (RHO2074), which may be obtained from Rhodia, Inc., under the tradename Rhodorsil Photoinitiator 2074; and combinations thereof. (4-n-octyloxyphenyl)phenyliodonium hexafluoroantimonate (OPIA) is shown in FIG. 24, [4-(2-

hydroxytetradecyloxyphenyl)]phenyliodonium hexafluoroantimonate (CD 1012) is shown in FIG. 25, and [4-1-methylethyl)phenyl](4-methylphenyl)iodonium tetrakis(pentafluorophenyl)borate(1-) (RHO2074) is shown in FIG. 26.

[0072] An alpha-dicarbonyl compound may be used as a photosensitizer. Examples of specific photosensitizers (PSs) that may be used in the composition of the present invention include, but are not limited to, (+/-) camphorquinone (CQ), which may be obtained from Aldrich under the number 12,489-2 with a 97% purity; 2-chlorothioxanthen-9-one(CTXO), which may be obtained from Aldrich C7 under the number 240-4; and combinations thereof. Camphorquinone (CQ) is shown in FIG. 27, and 2-chlorothioxanthen-9-one(CTXO) is shown in FIG. 28.

[0073] Examples of reaction promoters (RPs) that may be used in the composition of the present invention include, but are not limited to, ethyl p-dimethylaminobenzoate (EDMAB), which may be obtained from Acros under number 11840-1000 at 99+% purity; 4,4'-bis(diethylamino)benzophenone (BDEAB), which also may be obtained from Acros under number 17081-0250s at 99+% purity; and combinations thereof. Ethyl p-dimethylaminobenzoate (EDMAB) is shown in FIG. 29, and 4,4'-bis(diethylamino)benzophenone (BDEAB) is shown in FIG. 30.

[0074] The composition of the present invention is made by combining the above-described components together. The composition may then be cationically polymerized to form a dental matrix resin.

[0075] The dioxiranyl tetraoxaspiro[5.5]undecanes used in making the composition of the present invention are made by a series of reactions. First, an alkyl substituted unsaturated cyclohexenyl group bonded to a propane diol by a flexible alkylene, oxyalkylene, or an alkyleneoxy linkage is subjected to transesterification with tetra-alkyl-orthocarbonate to obtain an unsaturated

1,5,7,11-tetraoxaspiro[5.5]undecane (TOSU). Preferably, the flexible linkage is methylene, oxymethylene, or methyleneoxy. Preferable the tetra-alkyl orthocarbonate is tetra-ethyl orthocarbonate. This TOSU is then epoxidized with an organic per-acid to obtain a 1,5,7,11-dioxiranyl tetraoxaspiro[5.5]undecanes (TOSU). Preferably, the per-acid is metachloro-per-benzoic acid (MCPBA). The TOSUs listed above are novel compounds made by the method outlined above.

Examples 1-7, which follow, illustrate photopolymerizable mixtures of the present invention that have been formulated, polymerized, and characterized. Examples 8-10, which follow, show methods of making various novel TOSUs. These examples are not meant to limit the scope of this invention in any way.

EXAMPLE 1

[0076] Selected TOSU/BOCPE formulations representing 16 combinations of four different TOSUs (DOTSHH, DEODSH, BOCHM, BMOCHM) at four concentration levels (0.5, 1, 5, 10 wt%); one PI (OPIA); one PS (CQ); and one RP (EDMAB) were subjected to PDSC analysis. The amounts of components in the various formulations are shown in Table 1.

Table 1. TOSU/BOCPE Photopolymerizable Compositions

No.	Dioxirane	TOSU	Wt.%	No.	Dioxirane	TOSU	Wt.%
1	BOCPE	None	0	10	BOCPE	BOCHM	0.5
				11	BOCPE	BOCHM	1
2	BOCPE	DOTSHH	0.5	12	BOCPE	BOCHM	5
3	BOCPE	DOTSHH	1	13	BOCPE	BOCHM	10
4	BOCPE	DOTSHH	5				
5	BOCPE	DOTSHH	10	14	BOCPE	BMOCHM	0.5
				15	BOCPE	BMOCHM	1
6	BOCPE	DEODSH	0.5	16	BOCPE	BMOCHM	5
7	BOCPE	DEODSH	1	17	BOCPE	BMOCHM	10
8	BOCPE	DEODSH	5				
9	BOCPE	DEODSH	10				

Note: Photoinitiator system: OPIA/CQ/EDMAB = 1/0.5/0.1 wt %

[0077] A comparison of the compositional and PDSC data is shown in Table 2. This data suggests that increasing the concentration of TOSU in the polymerize mixture increases the polymerization rate as indicated by shorter exotherm peak maximum times.

Table 2. TOSU/BOCPE Photopolymerization Characteristics at 37°C

No.	ΔH (J/g)	Ind. time (sec)	Peak max. (sec)	k (min ⁻¹)	Peak max. time improvement (%)
1	282	32	84	1.5	Reference
2	311	27	79	4.0	6
3	284	35	77	5.5	8
4	321	21	57	2.1	32
5	289	22	46	6.4	45
6	318	34	96	3.1	0
7	266	32	76	2.5	0
8	319	24	70	3.2	0
9	312	23	67	2.8	0
10	296	29	77	4.4	11
11	330	22	64	2.4	24
12	311	18	43	1.2	49
13	295	17	40	1.0	52
14	330	22	76	4.6	10
15	341	22	74	1.7	12
16	304	20	53	1.5	37
17	320	23	62	1.7	26

Photopolymerization Conditions: 20 min. irradiation; > 418 nm; 8.2 mW/cm²

EXAMPLE 2

[0078] Selected TOSU/UVR-6105 formulations representing nine combinations of three different TOSUs (BOCHM, BCHEM, BMOCHM); three concentration levels (5, 10, 15 wt%); 1 PI (OPIA); one PS (CQ); one RP (EDMAB) and one temperature (37°C) were subjected to PDSC analysis. The amounts of components in the various formulations are shown in Table 3.

Table 3. TOSU/UVR 6105 Photopolymerizable Compositions

No.	Dioxirane	TOSU	TOSU Wt. %
18	UVR 6105	None	0
19	UVR 6105	BOCHM	5
20	UVR 6105	BOCHM	10
21	UVR 6105	BOCHM	15
22	UVR 6105	BCHEM	5
23	UVR 6105	BCHEM	10
24	UVR 6105	BCHEM	15
25	UVR 6105	BMOCHM	5
26	UVR 6105	BMOCHM	10
26	UVR 6105	BMOCHM	15
28	UVR 6105	BMOCHM	30

Note: Photoinitiator System: OPIA/CQ/EDMAB = 1/0.5/0.1 wt %

[0079] A comparison of the composition and results of the PDSC data is summarized in Table 4. This data indicates that the presence of TOSU monomers only slightly reduce the exothermicity and the rate of all photo-reactions.

Table 4. TOSU/UVR 6105 Photopolymerization Characteristics at 37°C

No.	ΔH (J/g)	Ind. time (sec)	Peak max. (sec)	k (min ⁻¹)
18	215	10	17	0.22
19	158	11	20	0.23
20	185	11	20	0.18
21	149	12	22	0.16
22	116	11	21	0.97
23	182	13	25	0.42
24	160	15	28	0.38
25	135	11	19	0.31
26	170	9	17	1.10
27	163	13	23	0.28
28	140	20	37	0.14

Photopolymerization Conditions: 20 min. irradiation; > 418 nm; 8.2 mWcm²

EXAMPLE 3

[0080] Selected TOSU/UVR-6105/PTHF formulations representing 14 different combinations of two different TOSUs (BOCHM, BMOCHM) at seven concentration levels (0.5, 1, 5, 10, 15, 20, 25 wt%) and one TOSU (BCHEM) at three concentration levels (5, 10, 15 wt%) were prepared with other variables held constant: one PI (OPIA); one PS (CQ); one RP (EDMAB); one temperature (37°C). The amounts of components in the various formulations are shown in Table 5.

Table 5. TOSU/UVR 6105/PTHF Photopolymerizable Compositions

No.	Dioxirane	Wt. %	Polyol	Wt. %	TOSU	Wt. %
29	UVR 6105	80	PTHF	20	None	0
30	UVR 6105	79.6	PTHF	19.9	BOCHM	0.5
31	UVR 6105	79.2	PTHF	19.8	BOCHM	1
32	UVR 6105	76	PTHF	19	BOCHM	5
33	UVR 6105	72	PTHF	18	BOCHM	10
34	UVR 6105	68	PTHF	17	BOCHM	15
35	UVR 6105	64	PTHF	16	BOCHM	20
36	UVR 6105	60	PTHF	15	BOCHM	25
37	UVR 6105	76	PTHF	19	BCHEM	5
38	UVR 6105	72	PTHF	18	BCHEM	10
39	UVR 6105	68	PTHF	17	BCHEM	15
40	UVR 6105	79.6	PTHF	19.9	BMOCHM	0.5
41	UVR 6105	79.2	PTHF	19.8	BMOCHM	1
42	UVR 6105	76	PTHF	19	BMOCHM	5
43	UVR 6105	72	PTHF	18	BMOCHM	10
44	UVR 6105	68	PTHF	17	BMOCHM	15
45	UVR 6105	64	PTHF	16	BMOCHM	20
46	UVR 6105	60	PTHF	15	BMOCHM	25

Note: Photoinitiator System: OPIA/CQ/EDMAB = 1/0.5/0.1 wt %

[0081] The results of the PDSC analysis are shown in Table 6. These results indicate that increasing the concentration of TOSU up to about 10 wt% generally increases the exothermicity of reaction as indicated by heat of reaction (ΔH).

Table 6. TOSU/UVR 6105/PTHF Photopolymerization Characteristics at 37°C

No.	ΔH (J/g)	Ind. time (sec)	Peak max. (sec)	k (min ⁻¹)
29	249	10	18	10.8
30	288	12	24	9.2
31	273	11	21	7.0
32	258	11	21	6.8
33	307	9	20	9.3
34	274	11	28	7.1
35	261	10	28	7.0
36	144	16	53	1.2
37	264	14	25	8.3
38	300	15	32	5.2
39	280	13	32	5.8
40	178	7	19	5.1
41	309	11	20	9.9
42	312	12	20	10.6
43	327	10	16	10.4
44	298	10	18	10.8
45	235	23	42	5.8
46	263	17	36	7.7

Photopolymerization Conditions: 20 min. irradiation; > 418 nm; 8.2 mW/cm²

EXAMPLE 4

[0082] Selected TOSU/UVR-6105/PTHF formulations representing six different combinations of three different TOSUs (BOCHM, BCHEM, BMOCHM) at two concentration levels (10, 25 wt%) were prepared and tested with other variables held constant: one PI (OPIA); one PS (CQ); one RP (EDMAB); and one test temperature (60°C). The amounts of components in the various formulations are shown in Table 7.

Table 7. TOSU/UVR 6105/PTHF Photopolymerizable Compositions

No.	Dioxirane	Wt. %	Polyol	Wt. %	TOSU	Wt. 5
29	UVR 6105	80	PTHF	20	None	0
33	UVR 6105	72	PTHF	18	BOCHM	10
36	UVR 6105	59.7	PTHF	14.9	BOCHM	25
43	UVR 6105	72	PTHF	18	BMOCHM	10
46	UVR 6105	60	PTHF	15	BMOCHM	25
47	UVR 6105	60	PTHF	16	BMOCHM	25

Note: Photoinitiator System: OPIA/CQ/EDMAB = 1/0. 5/0.1 wt%

[0083] The results of the PDSC analysis are shown in Table 8. These results demonstrate that addition of the TOSU monomer to the UVR-6105/PTHF base stock generally reduced the exothermicity and the rate of polymerization of the base stock.

Table 8. TOSU/UVR 6105/PTHF Photopolymerization Characteristics at 60°C

No.	ΔH (J/g)	Ind. time (sec)	Peak max. (sec)	k (min ⁻¹)
29	598	9	20	7.4
33	272	8	23	9.5
36	319	9	24	9.5
43	344	13	28	7.9
46	293	16	33	6.8
47	281	13	34	4.6

Photopolymerization Conditions: 20 min. irradiation; > 418 nm; 8.2 mW/cm²

EXAMPLE 5

[0084] The effect of irradiation time on the photoinitiated homopolymerization of BMOCHM-TOSU monomer (20 wt% in methylene chloride) was evaluated by gel point determination and by FTIR spectroscopy. Selected IR absorption bands in the reaction mixture characteristic of hydroxyl, carbonyl and oxirane groups were monitored as a function of irradiation time. The results of the FTIR analysis are shown in Table 9. The results of the FTIR analysis shows: (a) growth in the hydroxyl band which may indicate oxirane, and or spiro ring opening; (b) growth in the carbonyl region which indicates spiro ring protonation and/or spiro ring opening; and (c) diminishment in the oxirane band indicating opening of the oxirane ring. These observations indicate the possibility of homopolymer formation. The mixture gelled 1.5 min post irradiation.

Table 9. Photoinitiated Solution Homopolymerization of BMOCHM-TOSU

Irradiation time (min)	IR absorbance region R_x/R_0 ratio		
	Hydroxyl	Carbonyl	Oxirane
	3522 - 3418 cm^{-1}	1754 - 1744 cm^{-1}	905 cm^{-1}
0.5	1.08	1.06	0.96
1	1.24	1.14	0.95
2	1.67	1.45	0.84
4	4.12	3.22	0.68
6	5.91	3.23	0.47
8	5.25	2.64	0.35

R_x = [Band of Interest Absorbance/Reference Band Absorbance] at Time X

R_0 = [Band of Interest Absorbance/Reference Band Absorbance] at Time 0

Photoinitiator system: Gelest OMAN072/CQ/EDMAB = 3/1/0.1 wt %

Polymerization: 20 wt % in methylene chloride; 26°C; 3M XL 2500 Dental Curing Lamp—8min; 923 mW/cm².

[0085] The effect of irradiation time on the photoinitiated solution copolymerization of an equimolar mixture of BMOCHM-TOSU monomer and EPON 825 (20 wt% in methylene dichloride) was analyzed by gel point determination and via an FTIR spectroscopic method. Selected IR absorption bands in the copolymerization mixture characteristic of oxirane functionality in each of the monomers were monitored as a function of irradiation time. The results of these tests are shown in Table 10. The results clearly show: TOSU oxirane conversion proceeded at a faster rate and to a higher degree than EPON 825 oxirane conversion. Mixture gelled 1 min post irradiation. Growth in absorbance bands in the carbonyl and hydroxyl regions were similar to those observed during BMOCHM-TOSU homopolymerization.

Table 10. Photoinitiated Solution Copolymerization of BMOCHM-TOSU/EPON 825

Irradiation time (min)	Oxirane conversion (%)	
	EPON 825	BMOCHM-TOSU
	916 cm ⁻¹	905 cm ⁻¹
1	3.1	5.5
2	4.5	10.6
3	4.3	14.0
4	4.9	14.9
5	8.3	21.8
6	11.9	26.7
7	12.8	26.9

% Conversion. = $\{[(A_{OX}/A_{REF})_{time\ 0} - (A_{OX}/A_{REF})_{time\ 1}] / (A_{OX}/A_{REF})_{time\ 0}\} \times 100$ where A_{OX} = oxirane band absorbance; A_{REF} = aromatic (1608 cm⁻¹) reference band absorbance. Photoinitiator System: Gelest OMAN072/EDMAB = 3/1/0.1 wt %. Photopolymerization: Equimolar mixture (20 wt %) in methylene chloride; 25°C; 3M XL 2500 Dental Curing Lamp—8 min; 899 mW/cm².

EXAMPLE 6

[0086] The solubility of seven structurally different TOSUs (DEODSH, DOTSHH, DEODSHX, DOTSHX, BOCHM, BOMOCHM, AND BCHEM) were determined at 25°C in four different oxirane bases (BOCPE, BDDGE/PTHF, UVR 6105 and UVR 6105/PTHF). The results are summarized in Table 11. These results demonstrate that the DOTSHH TOSU which has a very rigid trispirocyclic structure is significantly less soluble than the other six TOSU with the less rigid, more flexible structures.

Table 11. Solubility of Selected TOSUs in Oxirane Coreactant Systems

		Oxirane base		
		BDDGE/PTHF	UVR	UVR 6105/PTHF
TOSU	BOCPE	(80/20)	6105	(80/20)
DEODSH ^a	> 10 wt %	—	—	40 wt %
DOTSHH ^b	10 wt %	5 wt %	—	< 5 wt %
DEODSHX ^{a,e}	—	—	—	30 wt %
DOTSHX ^{b,f}	< 5 wt %	< 5 wt %	—	—
BOCHM ^c	<10 wt %	—	30 wt %	25 wt %
BMOCHM ^c	< 10 wt %	—	30 wt %	25 wt %
BCHEM ^d	—	—	15 - 25 wt %	25 wt %

^a fused-ring monooxirane

^b fused-ring dioxirane

^c flexible-linked fused-ring dioxirane

^d unsaturated flexible-linked fused-ring

^e 5,5-diethyl-18-oxadispiro[1,3-dioxane-2,2'-1,3-dioxane-5'3'']-bicyclo[3.1.0]hexane]

^f 6,24-dioxatrispiro[bicyclo[3.1.0]hexane-3,5'-1,3-dioxane-2,2'-1,3-dioxane-5'3'']-bicyclo[3.1.0]hexane]

EXAMPLE 7

[0087] Formulations containing a TOSU (BOCHM, BMOCHM, or BCHEM), and a dioxirane (BOCPE or UVR 6105) or a dioxirane/polyol mixture (UVR 6105 and PTHF), were polymerized in bulk using a conventional dental curing light. The compositions tested and a description of the resultant products are given in Table 12. The photoinitiator system was OPIA/CQ/EDMAB 1/0.5/0.1 wt%. ~ 60 mg samples were placed in Teflon molds and irradiated at a distance of ~ 2 mm using a 3M XL3000 dental curing lamp (400 to 500 nm; ~ 500 mW/cm²) for selected time periods (0.5 to 4 min). When possible, before products were fully cured, a post-irradiation FTIR spectrum was obtained to characterize the polymerizates. All products eventually cured to hard solids.

Table 12. TOSU/UVR 6105/PTHF Bulk Photopolymerization Compositions and Products

No.	Dioxirane	Wt. %	Polyol	Wt. %	TOSU	Wt. %	Solid product
13	BOCPE	90	None	0	BOCHM	10	clear; yellow
17	BOCPE	90	None	0	BMOCHM	10	clear; orange
19	UVR 6105	95	None	0	BOCHM	5	clear; colorless
20	UVR 6105	90	None	0	BOCHM	10	clear; colorless
21	UVR 6105	85	None	0	BOCHM	15	clear; colorless
22	UVR 6105	95	None	0	BCHEM	5	clear; colorless
23	UVR 6105	90	None	0	BCHEM	10	clear; colorless
24	UVR 6105	85	None	0	BCHEM	15	clear; colorless
32	UVR 6105	76	PTHF	19	BOCHM	5	clear; colorless
33	UVR 6105	72	PTHF	18	BOCHM	10	clear; pale yellow
34	UVR 6105	68	PTHF	17	BOCHM	15	clear; colorless
37	UVR 6105	76	PTHF	19	BCHEM	5	clear; pale yellow
38	UVR 6105	72	PTHF	18	BOCHM	10	clear; colorless
39	UVR 6105	68	PTHF	17	BCHEM	15	clear; colorless
42	UVR 6105	76	PTHF	19	BMOCHM	5	clear; pale yellow
43	UVR 6105	72	PTHF	18	BOCHM	10	clear; colorless
44	UVR 6105	68	PTHF	17	BMOCHM	15	clear; pale yellow

Note: Photoinitiator System: OPIA/CQ/EDMAB = 1/0.5/0.1 wt 5 %

Photopolymerization Conditions: ~ 60 mg sample in Teflon mold; 3M XL3000 curing light 400 -500nm; ~ 500 mW/cm²; selected irradiation times; 2 mm distance; final cure upon standing at R. T.).

EXAMPLE 8

[0088] 3,9-Bis(cyclohex-3-enylmethyl)-1,5,7,11-tetraoxaspiro[5,5]undecane (BCHEM) and 3,9-bis[(7-oxabicyclo[4.1.0]hept-3-yl)methyl]-1,5,7,11-tetraoxaspiro[5.5]undecane (BOCHM) were prepared. The synthetic sequence employed in the preparation of these diepoxy tetraoxaspiro[5.5]undecane is shown in FIG. 31. The diethyl malonate precursor of the coupling diol was prepared by methods known in the art.

[0089] To a flame-dried 2L round-bottomed flask were placed LiAlH₄ (Aldrich, 95%, 29.03 g, 727 mmol) and anhydrous ethyl ether (10 mL). The resulting suspension was cooled to 0°C with stirring. To this cold suspension was then added dropwise a solution of 3-cyclohexene-1-carboxic

acid methyl ester (TCI America, 97%, 100 g, 98 mL, 692 mmol) in ether (100 mL). Bubbles evolved during the course of addition. The resulting mixture was allowed to stir for an hour at 0°C. The cold bath was then removed, and the reaction mixture was allowed to stir for an additional 2 hours at room temperature. The reaction mixture was again cooled to 0°C, and the reaction was quenched by dropwise addition of methanol (10 mL). The resulting mixture was then slowly poured into a pre-cooled aqueous solution of saturated Rochelle salt ($\text{NaKC}_4\text{H}_4\text{O}_6 \cdot 4\text{H}_2\text{O}$, potassium sodium tartrate tetrahydrate, 1500 mL) at 0°C. The resulting mixture was allowed to stir while being slowly warmed to room temperature, and the metal gray solid became white. The aqueous phase was extracted with ethyl ether (4x750 mL). The organic phases were combined, washed with water (4x750 mL), dried over anhydrous Na_2SO_4 , filtered and concentrated under reduced pressure to provide a colorless liquid which was shown to be fairly pure by GC (mainly one peak) and TLC (silica gel, 10% or 30% Et_2O /hexanes, mainly one spot) analyses. The crude material was subject to vacuum distillation and the desired alcohol, 3-cyclohexene-1-methanol, was collected as a colorless oil at 93-96°C/~20 mmHg in 99% yield. Bp (DSC) 204.44°C, 93-96°C/20 mmHg; ^1H -NMR (CDCl_3 , 300 MHz) δ 5.65 (m, 2H), 3.50-3.47 (dd, 2H, $J=6$, 2.4 Hz), 2.52-2.38 (m, 1H), 2.16-1.99 (m, 3H), 1.84-1.64 (m, 3H), 1.32-1.16 (m, 1H); ^{13}C -NMR (CDCl_3 , 300 MHz) δ 126.98, 125.79, 67.47, 36.11, 27.99, 25.11, 24.49; FT-IR (neat) (cm^{-1}) 3310, 3019, 2913, 2835, 1652, 1434, 1260, 1188, 1140, 1091, 1024, 966, 937, 738, 729, 651.

[0090] To a flame-dried three-necked 1L round-bottomed flask equipped with a magnetic stir bar, a condenser, a dropping funnel, and a thermometer was placed a mixture of thionyl chloride (Aldrich, 99+%, 41.26 mL, 67.3 g, 560 mmol), benzene (100 mL) and N,N -dimethylformamide (Aldrich, anhydrous 4 drops). To this mixture at room temperature was added dropwise a solution

of 3-cyclohexene-1-methanol (44.87 g, 400 mmol) in benzene (200 mL) through the dropping funnel over a period of 90 minutes (bubbles evolved). The resulting mixture was then brought to 60°C and maintained at this temperature for an additional 4 hours (a lot more bubbles). The reaction mixture was allowed to slowly cool to room temperature and stirred overnight. The mixture was transferred to a 1L round-bottomed flask, and the solvent along with volatile by-products were removed under reduced pressure. The light yellow residue liquid was subject to vacuum distillation, and the desired product, 3-cyclohexene-1-chloromethane, was collected at 58-60°C/~20 mmHg as a colorless liquid in 87% yield. (The colorless chloride compound turned brownish yellow over a period of 5 days). Bp 58-60°C/20 mmHg; ¹H-NMR (CDCl₃, 300 MHz) δ 5.67 (m, 2H), 3.48-3.45 (d, 2H, J=6.3 Hz), 2.26-1.76 (m, 6H), 1.44-1.30 (m, 1H); ¹³C-NMR (CDCl₃, 300 MHz) δ 126.88, 125.26, 50.07, 36.14, 29.24, 26.27, 24.51; FTIR (neat) (cm⁻¹) 3019, 2913, 2835, 1657, 1434, 1309, 1260, 1140, 1043, 917, 743, 719, 651.

[0091] Sodium ethoxide (NaOEt) was prepared in situ as follow: To a flame-dried three-necked 500 mL round-bottomed flask equipped with a magnetic stir bar, a condenser, a dropping funnel, and a thermometer were placed sodium metal (6.90 g, 300 mmol) and anhydrous ethanol (160 mL). The mixture was allowed to react at room temperature with stirring until all the sodium metal was consumed.

[0092] The above in-situ generated sodium ethoxide solution was brought to 70°C and then diethyl malonate (Aldrich, 99%, 46 mL, 300 mmol) was added dropwise through the dropping funnel over a period of 30 minutes. The resulting mixture was allowed to stir at 70°C for an additional 30 minutes after the completion of the malonate addition. To this mixture was then added dropwise a solution of 3-cyclohexene-1-chloromethane (39.19 g, 300 mmol) in absolute ethanol (100 mL)

through the dropping funnel over a period of 45 minutes. The resulting mixture was brought to reflux (white solid formed after 30 minutes of refluxing) after the completion of addition and was maintained at reflux temperature for 24 hours while monitored by TLC (silica gel, 20% Et²O/hexanes). The reaction mixture was allowed to cool to room temperature, and the solvent was removed under reduced pressure. The residue was taken up with a mixture of water (450 mL) and diethyl ether (100 mL). The aqueous phase was separated and extracted with diethyl ether (3x350mL). The combined organic phase was dried over anhydrous magnesium sulfate, filtered, and concentrated under reduced pressure to provide a light yellow liquid product (62.06 g, 81.35% crude yield). The crude material was subject to vacuum distillation and the desired diethyl 2-(3-cyclohexene-1-methyl)malonate was collected at 145-147°C/0.75 mmHg as a colorless liquid in 48% yield. Bp 145-147°C/0.75 mmHg; ¹H-NMR (CDCl₃, 300 MHz) δ 5.59 (m, 2H)m, 4.18-4.10 (q, 4H, J=7.2 Hz), 3.44-3.37 (t, 1H, J=7.8 Hz), 2.13-1.40 (m, 9H), 1.22 (t, 6H, J=7.2Hz); ¹³C-NMR (CDCl₃, 300 MHz) δ 169.50, 126.82, 125.71, 61.16, 49.54, 35.14, 31.32, 31.21, 28.34, 24.77, 13.93; FTIR (neat) (cm⁻¹) 3019, 2981, 2913, 1749, 1729, 1444, 1367, 1304, 1270, 1236, 1193, 1149, 1096, 1028.

[0093] To a flame-dried 1 L round-bottomed flask was placed a mixture of lithium aluminum hydride powder (Aldrich, 95%, 9.98 g, 249.7 mmol) and anhydrous diethyl ether (200 mL). The mixture was allowed to stir while cooling to 0°C. To this cold LAH suspension was then added dropwise a solution of diethyl 2-(3'-cyclohexene-1'-methyl)malonate (25.20 g, 103 mmol) in anhydrous diethyl ether (50 mL) through a dropping funnel over a period of 30 minutes. The resulting mixture was allowed to stir for an hour at 0°C and then slowly warmed to room temperature. The reaction mixture was allowed to stir at room temperature for an additional 3 hours.

The reaction mixture was then diluted with diethyl ether (250 mL), cooled to 0°C, and quenched by dropwise addition of methanol (25 mL). The resulting mixture was allowed to stir for 30 minutes and then slowly poured into an aqueous solution of saturated Rochelle salt (500 mL) at 0°C. The resulting mixture was allowed to stir while it slowly came to room temperature and the gray metal solid became white. The aqueous layer was separated and extracted with diethyl ether (2x700 mL). The combined organic phase was washed with water (2x750 mL), dried over anhydrous sodium sulfate, filtered and concentrated under reduced pressure to give a white solid (95.5% crude yield) which was shown to be a mixture of 4 components by GC analysis. The crude material was purified by recrystallization from diethyl ether/hexanes (1/4 v/v). The desired 2-(3-cyclohexene-1-methyl)-1,3-propanediol was obtained as white needle crystalines in 82% yield. Mp (DSC) 86.9°C; ¹H-NMR (CDCl₃, 300 MHz) δ 5.65 (m, 2H), 3.89-3.76 (m, 2H), 3.68-3.61 (m, 2H), 2.76 (s, 2H), 2.18-1.86 (m, 4H), 1.79-1.53 (m, 3H), 1.28-1.11 (m, 3H); ¹³C-NMR (CDCl₃, 300 MHz) δ 127.06, 126.18, 66.97, 66.70, 38.74, 34.44, 32.02, 30.74, 29.05, 25.08; FTIR (KBr pellet) (cm⁻¹) 3291, 3019, 2903.

[0094] To a three-necked 500 mL round-bottomed flask equipped with a magnetic stir bar, a Dean-Stark trap, a condenser and a thermometer was placed a mixture of toluene (300 mL) and 2-(3-cyclohexene-1-methyl)-1,3-propanediol (13.62 g, 80 ml). The starting diol solid did not dissolve in toluene until it was heated up to 45°C. The solution was maintained at reflux for an hour and 25 mL of azeotropical mixture was removed from the Dean-Stark trap. The mixture was allowed to cool to room temperature and then anhydrous p-toluene sulphonic acid (PTSA, 0.23 g) was added, followed by the addition of tetraethyl orthocarbonate (TEOC, 8.4 mL, 40 mmol). The resulting mixture was then brought to reflux to azeotropically remove, through the Dean-Stark trap, the by-product ethanol thus formed during the reaction. The azeotropic mixture was shaken with salty

water to determine the amount of ethanol collected. After removing 180 mL of the azeotropic mixture, the reaction mixture was maintained at ~108°C overnight. The reaction mixture was allowed to cool to room temperature (no solid precipitated) and then triethylamine (1.5 mL) was added. The resulting mixture was allowed to stir for a half hour, transferred to a 500 mL round-bottomed flask and concentrated under reduced pressure to give a white solid, which was not soluble in diethyl ether but was soluble in methylene chloride. The crude material was purified by recrystallization from boiling diethyl ether. The desired product 3,9-bis[(3-cyclohexenyl)methyl]-1,5,7,11-tetraoxaspiro[5.5]undecane was obtained as white crystals in 70% yield. Mp (DSC) 100.83°C; ¹H-NMR (CDCl₃, 300 MHz) δ 5.63 (s, 4H), 4.20-3.87 (m, 4H), 3.84-3.74 (dt, 2H, J=9.6, 3.9 Hz), 3.68-3.59 (dt, 2H, J=9.6, 3.9 Hz), 2.18-1.98 (m, 8H), 1.78-1.46 (m, 6H), 1.34-1.08 (m, 6H); ¹³C-NMR (CDCl₃, 300 MHz) δ 127.00, 125.98, 114.35, 67.33, 67.17, 66.79, 66.63, 34.72, 31.84, 31.81, 30.39, 30.05, 28.94, 28.89, 24.94; FTIR (evaporation of CDCl₃ solution) (cm⁻¹) 3056, 3024, 2974, 2840, 1652, 1458, 1436, 1376, 1266, 1244, 1211, 1182, 1138, 1112, 704, 656; Anal. Calcd. for C₂₁H₃₂O₄: C, 72.38; H, 9.26; Found: C, 72.43; H, 9.54. The ¹H-NMR Spectrum, the ¹³C-NMR Spectrum, and the FTIR Spectrum of 3,9-bis[(3'-cyclohexenyl)methyl]1,5,7,11-tetraoxaspiro[5.5]undecane (BCHEM) are shown in FIGS. 32-34, respectively.

[0095] 3,9-Bis[(7-oxabicyclo[4.1.0]hept-3-yl)methyl]1,5,7,11-tetraoxaspiro[5.5]undecane (BOCHM) was prepared employing biphasic epoxidation due to the acid sensitive nature the compound. To a 500 mL round-bottomed flask was placed a mixture of 3,9-bis[(3-cyclohexenyl)methyl]-1,5,7,11-tetraoxaspiro[5.5]undecane (BCHEM-TOSU 4, 3.48 g, 10 mmol) and 150 mL of methylene chloride (CH₂Cl₂). To this solution was added 0.5 M aqueous solution of sodium bicarbonate (62 mL, pH~8). The resulting biphasic mixture was allowed to stir vigorously

at room temperature and then m-chloroperbenzoic acid (Aldrich, 77% max., mCPBA, 4.53 g, ~20.2 mmol) was slowly added in several portions over a period of 30 minutes. The resulting mixture was allowed to stir for an additional 5 hours at room temperature, and the reaction progress was monitored by TLC (silica gel, 25% ether/hexanes). The two phases were separated, and the organic phase was washed successively with 1 N aqueous NaOH (2x75 mL) and water (2x75 mL). The combined aqueous phase was back extracted with methylene chloride (2x100 mL). The organic phases were combined, dried over anhydrous Na₂SO₄, and concentrated under reduced pressure to give a white solid. The crude material was washed with 5 mL of cold ether (pre-cooled at 0°C) and purified by flash chromatography (silica gel, 15% ethyl ether/hexanes) or by recrystallization two times from diethyl ether/hexanes (the crude material was dissolved in refluxing ether, allowed to cool to room temperature and then hexanes were slowly added). The desired product BOCHM-TOSU was obtained as white crystals in 91% yield. Mp (DSC) 110.56°, (capillary) 105-106°C; ¹H-NMR (CDCl₃, 300 MHz) δ 3.98-3.82 (m, 4H), 3.76-3.67 (dt, 2H, J=9.5, 3.9 Hz), 3.62-3.52 (dt, 2H, J=9.5, 3.9 Hz), 3.16-3.06 (m, 4H), 2.17-1.92 (m, 6H), 1.86-1.62 (m, 2H), 1.50-0.98 (m, 11H), 0.93-0.77 (m, 1H); ¹³C-NMR (CDCl₃, 300 MHz) δ 114.26, 67.08, 67.03, 66.88, 66.59, 66.52, 66.48, 66.44, 52.84, 52.34, 51.67, 51.39, 34.98, 34.95, 34.49, 32.00, 31.94, 30.77, 30.65, 29.89, 29.85, 29.56, 27.21, 26.45, 24.99, 24.56, 24.42, 23.34; FTIR (evaporation of CDCl₃, solution) (cm⁻¹) 3056, 2986, 2927, 1474, 1458, 1434, 1377, 1266, 1212, 1195, 1149, 1115, 902, 809, 785, 704; Anal. Calcd. for C₂₁H₃₂O₆: C, 66.29; H, 8.48; Found: C, 66.03; H, 8.64. The ¹H-NMR Spectrum, the ¹³C-NMR Spectrum, and the FTIR Spectrum of 3,9-bis[(7-oxabicyclo[4.1.0]hept-3-yl)methyl]1,5,7,11-tetraoxaspiro[5.5]undecane (BOCHM) are shown in FIGS. 35-37, respectively.

EXAMPLE 9

[0096] 3, 9-Bis[(6-methylcyclohex-3-enyl)methyl]-1,5,7,11-tetraoxaspiro[5,5]undecane (BMCHEM) and 3, 9-bis[(4-methyl-7-oxabicyclo[4.1.0]hept-3-yl)methyl]-1,5,7,11-tetraoxaspiro[5,5]undecane (BMOCHM) were prepared. The synthetic sequence employed in the preparation of this diepoxy spiroorthocarbonate is shown in FIG. 38.

[0097] The following chloro-, -diacetate, -diol cyclohexene compounds were prepared as follows: To an oven dried three-necked round bottomed 500mL flask, equipped with an additional funnel, a reflux condenser, a thermometer, a magnetic stirrer bar and a cooling bath, and blanketed with N₂ was charged with (1) 1-hydroxymethyl-6-methyl-3-cyclohexene 40.9 mL (Aldrich, 97%, 0.30 mole) in 150 mL benzene along with a few drops of anhydrous N,N-dimethylformamide. To this stirred solution thionyl chloride 31.0 mL (Aldrich, 99%, 0.42 mole) in 75 mL benzene was then added dropwise from the additional funnel. Not much exotherm was observed, although maintaining the reaction mixture at about 15°C was preferred due to much gas evolution. Upon completion of addition, the cooling bath was removed, and the reaction mixture was slowly brought up to and stirred at 60°C for two more hours while the color of the mixture turned from colorless to light amber to reddish brown. TLC (silica gel, ethyl ether/hexanes 1/1, V/V) showed the starting material (R_f0.33) had almost disappeared and a new spot (R_f0.7) formed. The reaction mixture was stripped of volatile compounds under reduced pressure and distilled in a 4" Vigreux column to produce the colorless liquid of a mixture of diastereomers of 1-chloromethyl-6-methyl-3-cyclohexene 39.5 g at 82-3°C/20 mmHg (yield 90.9%). ¹H-NMR (CDCl₃, 300 MHZ) δ 5.62-5.60 (m, 2H) 3.63-3.61 (m, 2H), 2.14-2.09 (m, 4H), 1.80-1.75 (m, 3H), 1.00-0.98, 0.88-0.86 (dd, 3H, J=6.0 Hz); ¹³C-NMR (CDCl₃, 300 MHZ) δ 126.01, 125.50, 124.59, 48.62, 46.93, 41.08, 39.78, 33.04, 32.26, 29.86, 28.50,

28.35, 26.42, 18.86, 14.19; FT-IR (neat, cm^{-1}) 3026, 2958, 2897, 2839, 1657, 1436, 1378, 1294, 1154, 1007, 891, 776, 723, 658; GC (Acetone; detector 300°C, injector 270°C, column: 60°C 12 min., 20°C/min to 260°C 5 min) (showed 1 peak at 7.1 min.) Anal. Calcd for $\text{C}_8\text{H}_{13}\text{Cl}$: 66.43; H, 9.06; Found: C, ; H.

[0098] An oven dried three-necked round bottomed 500 mL flask, equipped with an additional funnel, a reflux condenser, a thermometer, a magnetic stirrer bar and a cooling bath, and blanketed with N_2 was charged with anhydrous ethanol 190 mL. Sodium 8.61 g (Aldrich, 0.3745 mole) was then added in small pieces over a period of one hour. Upon completion of addition, the cooling bath was removed, and the mixture was heated to 70°C. 1-Chloromethyl-6-methyl-3-cyclohexene was then added. The reaction mixture was stirred for another 30 min, was brought up to reflux for 9 hours and left stirring overnight. The reaction was monitored with TLC (silica gel, Et_2O /hexanes $\frac{1}{2}$, V/V). Then, ethanol was mostly removed under reduced pressure, and water and ethyl ether were added to dissolve the resultant mixture. The organic phase was thus separated from the aqueous phase and washed with water 3X200 mL until the pH reached 7. The aqueous phase was back extracted with ether, and the extraction was washed with water to obtain pH 7. The washed organic phases were combined and dried over anhydrous MgSO_4 and was filtered and concentrated under reduced pressure. This resultant mixture was distilled to give 43.6 g of the colorless oil of 1-(6-methyl-3-cyclohexene)-2-methyl-propanediacetate at 155-7°C/6-7 mmHg (yield 43.3%). ^1H -NMR (CDCl_3 , 300 MHz) δ 5.60-5.50 (m, 2H), 4.19-4.11 (m, 4H), 3.44-3.38 (m, 1H), 2.24-2.10 (m, 3H), 1.67-1.58 (M, 4H), 1.25-1.19 9d, d, d, 6H, $J=3.9$ Hz), 0.96-0.92 (d, d, 3H, $J=3.9$ Hz); ^{13}C -NMR (CDCl_3 , 300 MHz) δ 169.77, 169.36, 126.08, 125.19, 61.23, 61.10, 49.67, 36.68, 32.86, 32.52, 32.38, 29.46, 19.38, 13.98; FT-IR (neat, cm^{-1}) 3024, 2980, 2905, 2832, 1733, 1657,

1445, 1369, 1250, 1193, 1151, 1031, 853, 664; GC (Et₂O; detector 300°C, injector 270°C, column: 60°C 5 min, 20°C/min to 260°C 7 min) (showed 1 peak @ 10.1 min.); Anal. Calcd. for C₁₅H₂₄O₄: C, 67.14; H 9.01; Found: C, 66.95; H, 9.27.

[0099] An oven dried three-necked round bottomed 500 mL flask, equipped with an additional funnel, a reflux condenser, a thermometer, a magnetic stirrer bar and a cooling bath, and blanketed with N₂ was charged with anhydrous diethyl ether 220 mL and lithium aluminum hydride, LAH 7.73 g (Aldrich, 95%, 0.1936 mole). To this suspension 1-(6-methyl-3-cyclohexene)-2-methylpropanediacetate (3) was added dropwise while maintaining a temperature of 3-5°C. Upon completion of addition, the reaction mixture was stirred for an additional hour at this temperature. Then it was brought up to reflux at 32-35°C for 2 hours followed by stirring at room temperature overnight. The reaction was monitored with TLC (silica gel, Et₂O/hexanes 1.5/1, V/V). The starting material (R_f 0.68) had disappeared and a new spot R_f 0.05 was observed. A saturated aqueous Rochelle salt 450mL and methanol 32 mL were then added to get rid of the excess LAH. Water was added to separate the organic phases from the slightly opaque aqueous phase. The organic phase was washed with 3X100 mL of water until the pH reached 7. The aqueous phase was back extracted with 4X200 mL Et₂O and was washed with water until the pH reached 7. The organic phases were combined, dried over MgSO₄, filtered and concentrated under reduced pressure to give a crude product. The latter was purified by flash chromatography (silica gel, ethyl acetate/hexanes ½ to 1/0) to obtain the colorless oil of 1-(6-Methyl-3-cyclohexane)-2-methylene-propanediol 11.0 g (96.2% yield). ¹H-NMR (CDCl₃, 300 MHz) δ 5.65-5.55 (m, 2H), 3.83-3.55 (m, 2H), 3.30 (s, 2H), 2.82-2.04 (m, 2H), 1.87-1.86 (m, 1H), 1.68-1.63 (m, 2H), 1.51-1.43 (m, 2H), 1.33-1.31 (m, 1H), 0.94-0.92 (m, 3H); ¹³C-NMR (CDCl₃, 300 MHz) δ 126.14, 125.57, 67.41, 65.53, 38.88, 36.07, 32.89, 32.79,

31.38, 30.3, 19.60; FT-IR (neat, cm^{-1}) 3324, 3022, 2961, 2903, 2880, 2825, 1660, 1463, 1443, 1377, 1030, 969, 659; GC (Et_2O ; detector 300°C , injector 270°C , column: 60°C 5 min, $20^\circ\text{C}/\text{min}$ to 260°C 7 min) (showed 2 peaks @ 12.1, 7.0 min.); Anal. Calcd. For $\text{C}_{11}\text{H}_{20}\text{O}_2$: C, 71.70, H, 10.94; Found: C, 71.26; H, 11.35.

[0100] A three-necked round bottomed 500mL flask, equipped with a Dean-Stark trap (20 mL), a reflux condenser, a thermometer, a magnetic stirrer bar was charged with 1-(6-Methyl-3-cyclohexane)-2-methylene-propanediol 10.95 g (0.0594 mole) and toluene 300 mL. The mixture was brought up to reflux and kept refluxing for 2 hours to azeotropically remove any moisture. About 40 mL of azeotropic mixture was collected in the trap. Then, blanketed with N_2 , the mixture was allowed to cool down to room temperature, and 0.2 g of anhydrous p-toluenesulfonic acid (p-TSA) was added, followed by a dropwise addition of tetraethylorthocarbonate² (TEOC) 6.3 mL (prepared in-house, GC purity 99.7%, 0.03 mole). The reaction mixture was then brought up to reflux to azeotropically remove EtOH generated during the reaction. The total azeotropic mixture collected from the Dean-Stark trap (135 mL) was shaken with salt water to determine the EtOH volume. (5.5 mL). TLC (silica gel, $\text{Et}_2\text{O}/\text{hexanes}$ 1/1, V/V) showed that the starting diol (R_f 0.04) had disappeared, and a new spot (R_f 0.68) was observed. The reaction mixture was now allowed to cool down to room temperature and was neutralized with 1 mL of triethylamine. The resulting mixture (pH ~ 8) was stirred for 30 min and was concentrated under reduced pressure. This crude oil was purified twice by flash chromatography 1 (silica gel, $\text{Et}_2\text{O}/\text{hexanes}$ 1/5.6 to 1/4, V/V) and flash chromatography 2 (silica gel, $\text{Et}_2\text{O}/\text{hexanes}$ 1/7 to 1/5, V/V). 3,9-Bis[1-methylene-2-(6-methyl-3-cyclohexene)]-1,5,7,11-tetraoxaspiro[5.5]undecane was obtained in 56.8% yield as a colorless, viscous oil. $^1\text{H-NMR}$ (CDCl_3 , 300MHz) δ 5.65-5.56 (m, 4H), 4.02-3.78 (m, 6H), 3.65-

3.58 (m, 2H), 2.20-2.05 (m, 6H), 1.72-1.58 (m, 5H), 1.50-1.40 (m, 4H), 1.06-1.04 (m, 2H), 1.00-0.91 (m, 7H); ^{13}C -NMR (CDCl_3 , 300MHz) δ 126.12, 125.41, 114.38, 67.78, 67.20, 66.88, 66.26, 35.75, 32.83, 32.71, 32.64, 31.67, 30.05, 29.87, 29.83, 19.54; FT-IR (neat, cm^{-1}) 3021, 2955, 2878, 1659, 1457, 1246, 1213, 1191, 1140, 1113, 1006, 660; Anal. Calcd. for $\text{C}_{23}\text{H}_{36}\text{O}_4$: C, 73.37; H, 9.64; Found: C, 73.09; H, 9.58. The ^1H -NMR Spectrum, the ^{13}C -NMR Spectrum, and the FTIR Spectrum of 3,9-bis-[1-methylene-2-(-6-methyl-3-cyclohexene)]-1,5,7,11-tetraoxaspiro[5,5]undecane (BMCHM) are shown in FIGS. 39-41, respectively.

[0101] The spiroorthocarbonate BMOCHM was prepared employing biphasic epoxidation due to the acid sensitive nature of this compound. A 1 L round bottomed flask was charged with a 3,9-bis[1-methylene-2-(-6methyl-3-cyclohexene)]-1,5,7,11-tetraoxaspiro[5,5]undecane 5.8 g (0.0154 mole) and methylene chloride (CH_2Cl_2) 230 mL. To this solution was added sodium bicarbonate 0.5 M aqueous solution 96 mL. The resultant mixture was allowed to stir vigorously at room temperature and then m-chloroperbenzoic acid, mCPBA (Aldrich, 77% max, 0.0316 mole) 8.6 g was added in several portions over a duration of 30 minutes. The reaction mixture was monitored by TLC (silica gel, Et_2O /hexanes 1/1, V/V) and thus stirred overnight. TLC showed the starting compound BMCHM RF 0.77 had disappeared and a new spot Rf 0.17 was present. The 2 phases were then separated, and the organic phase was washed twice with 1 N aqueous NaOH 150 mL followed with water (2X150 mL) until the pH reached ~ 7 . The aqueous phase was back extracted with Et_2O and was washed with NaOH/ H_2O likewise until the pH reached ~ 7 . The washed organic phases were combined, dried over anhydrous Na_2SO_4 and concentrated under reduced pressure to produce a crude viscous oil. This product was purified twice by flash chromatography (silica gel, 2% triethylamine, $\text{CH}_2\text{Cl}_2/\text{Et}_2\text{O}$ 12/1 to 4/1, V/V). After stripping the product of volatile materials

and drying it extensively under reduced pressure, a colorless amorphous material of a mixture of diastereomers of 3,9-bis[(4-methyl-7-oxabicyclo[4.1.0]hept-3-yl)methyl]-1,5,7,11-tetraoxaspiro[5.5]undecane 5.6 g (89.3% yield) was procured. ¹H-NMR (CDCl₃, 300MHz) δ 3.98-3.50 (m, 8H), 3.15-3.08 (m, 4H), 2.26-1.99 (m, 6H), 1.50-1.27 (m, 8H), 1.14-1.06 (m, 2H) 0.92-0.76 (m, 8H); ¹³C-NMR (CDCl₃, 300 MHz) δ 114, 67.76, 67.69, 67.15, 66.55, 65.97, 65.92, 52.72, 52.59, 51.75, 51.46, 35.47, 35.38, 34.24, 33.17, 32.85, 32.07, 31.63, 31.58, 31.19, 31.13, 31.09, 29.86, 29.77, 29.67, 29.10, 19.26, 19.22, 19.14; FT-IR (CH₂Cl₂, evaporated, cm⁻¹) 2971, 2942, 2921, 1458, 1249, 1214, 1143, 1113, 1008, 817, 768, 701; Anal. Calcd. For C₂₃H₃₆O₆: C, 67.62, H, 8.88; Found C, 67.17, H, 9.09. The ¹H-NMR Spectrum and the FTIR Spectrum of 3,9-bis[(4-methyl-7-oxabicyclo[4.1.0]hept-3-yl)methyl]-1,5,7,11-tetraoxaspiro[5.5]undecane (6) (BOCHM-TOSU) are shown in FIGS. 42-43, respectively.

EXAMPLE 10

[0102] 3,9-bis[2-methyl-7-oxabicyclo[4.1.0]hept-3-yl)methoxy]-1,5,7,11-tetraoxaspiro[5.5]undecane (BMCHEMO) and 3,9-bis[(4-methyl-7-oxabicyclo[4.1.0]hept-3-yl)methoxy]-1,5,7,11-tetraoxaspiro[5.5]undecane (BMOCHMO) were prepared. The synthetic sequence employed in the preparation of the diepoxidized cyclohexenymethoxy tetraoxaspiro[5.5]undecane is shown in FIG. 44.

[0103] To a flame-dried three-necked 1 L round-bottomed flask equipped with a magnetic stir bar, a reflux condenser, a dropping funnel, and a thermometer was placed sodium hydride (Aldrich, 60% dispersion in mineral oil, 31.68 g, 792 mmol) under an atmosphere of nitrogen. This NaH was washed with hexanes (3x150 mL) and the hexanes wash was removed via a syringe. The oil free NaH was allowed to dry by passing through a stream of nitrogen. To this oil free NaH was

added toluene (500 mL), and the resulting heterogeneous mixture was allowed to cool to 0°C. To the cold suspension was then added dropwise a solution of 6-methylcyclohex-enylmethanol (Aldrich, 97%, 103.04 g, 108 mL, 792 mmol) in toluene (100 mL) through the dropping funnel over a period of 60 minutes. Bubbles evolved and white solid formed. The resulting mixture was allowed to slowly warm to room temperature and stir overnight. The reaction mixture was brought to 70°C and stirred for 5 hours. (Note: stirring without heating yielded lower generation of the desired sodium alkoxide as shown by TLC analysis and the end result of the next coupling reaction.) The reaction mixture was allowed to cool to 0°C, and then a solution of diethyl 2-bromomalonate (Avocado, 95%, 60.40 g, 43.08 mL, 240 mmol) in toluene (50 mL) was added through the dropping funnel over a period of 30 minutes. The resulting mixture was allowed to stir at room temperature overnight. The white solid was consumed, and the reaction solution turned brown. The reaction mixture was washed with water (3x450 mL) and saturated aqueous solution of NaCl (500 mL) successfully. The aqueous phases were combined and back extracted with toluene (2x500 mL). The organic phases were combined, dried over anhydrous sodium sulfate, filtered and concentrated under reduced pressure to give reddish orange liquid. The crude material was subject to vacuum distillation and the product was collected at 170-235°C/0.75 mmHg as a mixture of the starting mono alcohol and diastereomers of possibly three diesters (di-6-methylcyclohex-3-enylmethyl-, diethyl- and ethyl 6-methylcyclohex-3-enylmethyl-). The distillate was purified by column chromatography (silica gel, 5% ethyl ether/hexanes). The desired product, di(6-methylcyclohex-3-enyl)methyl 2-[(6-methylcyclohex-3-enyl)methoxy]propane-1,3-dioate, was collected as a mixture of the three possible diesters in 15.5% yield (16.54 g). Note: Purification of the crude material by flash chromatography without prior distillation gave better results. The mixture of diesters was collected in 22.8% yield

(24.3 g) along with a mixture of the diesters and the starting mono alcohol (30.15 g). ¹H-NMR (CDCl₃, 300 MHz, diastereomeric mixture of possible diesters) δ 5.58 (m, 4H), 4.44-3.94 (m, 5H), 3.64-3.33 (m, 2H), 2.24-1.56 (m, 13H), 1.31-1.14 (m, 1H), 0.99-0.83 (m, 6H); ¹³C-NMR (CDCl₃, 300 MHz, diastereomeric mixture of possible diesters) δ 166.76, 166.58, 126.05, 125.72, 125.64, 125.57, 125.51, 125.22, 125.14, 124.94, 124.49, 124.4179.42, 74.10, 68.12, 67.88, 66.88, 41.59, 38.40, 35.91, 32.97, 32.00, 29.50, 29.45, 29.34, 27.74, 27.68, 27.62, 25.44, 19.20, 19.10, 14.75, 13.95; FTIR (neat) (cm⁻¹) 3024, 2960, 2899, 2837, 1744, 1655, 1458, 1436, 1381, 1265, 1148, 1013, 662.

[0104] To a flame-dried 1 L round-bottomed flask was placed a mixture of lithium aluminum hydride powder (Aldrich, 95%, 5.88 g, 147.2 mmol) and anhydrous diethyl ether (210 mL). The mixture was allowed to stir while cooling to 0°C. To this cold LAH suspension was then added dropwise a solution of di(6-methylcyclohex-3-enyl)methyl 2-[(6-methylcyclohex-3-enyl)methoxy]propane-1,3-dioate 1 (mixture as discussed above, 20.93 g, 47.07 mmol) in anhydrous diethyl ether (30 mL) through a dropping funnel over a period of 60 minutes. The resulting mixture was allowed to stir for five (5) hours at 0°C and then slowly warmed to room temperature. The reaction mixture was allowed to stir overnight at room temperature. The reaction mixture was then diluted with diethyl ether (250 mL), cooled to 0°C, and quenched by dropwise addition of methanol (25 mL). The resulting mixture was allowed to stir for 30 minutes and then slowly poured into an aqueous solution of saturated Rochelle salt (500 mL) at 0°C. The resulting mixture was allowed to stir while it slowly came to room temperature and the gray metal solid became white. The aqueous layer was separated and extracted with diethyl ether (2x300 mL). The combined organic phase was washed with water (2x500 mL), dried over anhydrous sodium sulfate, filtered and concentrated under

reduced pressure to give a pale yellow oil which was shown to be mainly a mixture of 6-methylcyclohex-3-enylmethanol by-product and the desired diol, 2-[(6-methylcyclohex-3-enyl)methoxy]propane-1,3-diol, by TLC analysis. The crude material was purified by column chromatography (silica gel, 50% diethyl ether/hexanes). The desired 2-[(6-methylcyclohex-3-enyl)methoxy]propane-1,3-diol was obtained as colorless liquid in 46.3% yield (4.36 g) along with 7.9% yield (0.74 g) of slightly impure product and a mixture (15.53 g) of the desired diol and 6-methylcyclohex-3-enylmethanol. ¹H-NMR (CDCl₃, 300 MHz) δ 5.59 (m, 2H), 3.77-3.55 (m, 5H), 3.51-3.36 (m, 2H), 2.65 (broad s, 2H), 2.22-1.22 (m, 6H), 0.97-0.82 (m, 3H); ¹³C-NMR (CDCl₃, 300 MHz) δ 126.00, 125.66, 79.70, 72.60, 61.86, 61.78, 39.64, 32.92, 29.57, 27.95, 19.33; FTIR (neat) (cm⁻¹) 3367, 3023, 2957, 2887, 2833, 1655, 1435, 1378, 1073, 659.

[0105] To a three-necked 250 mL flask equipped with a magnetic stir bar, a Dean-Stark trap, a reflux condenser and a thermometer was placed a mixture of toluene (150 mL) and 2-[(6-methylcyclohex-3-enyl)methoxy]propane-1,3-diol 2 (7.22 g, 36 mmol). The solution was brought to reflux to remove water azeotropically. The solution was maintained at reflux temperature for 2 hours, and 13 mL of azeotropical mixture was removed from the Dean-Stark trap. The mixture was allowed to cool to room temperature, and then anhydrous p-toluene sulphonic acid (PTSA, 0.15 g) was added followed by the addition of tetraethyl orthocarbonate (TEOC, 3.77 mL, 8.03 mmol) via a syringe. The resulting mixture was then brought to reflux to azeotropically remove, through the Dean-Stark trap, the by-product ethanol thus formed during the course of reaction. About 80 mL of the azeotropical mixture was removed, which contained 4.2 mL of ethanol (the azeotropic mixture was shaken with salty water to determine the amount of ethanol collected). The reaction mixture was allowed to stir overnight at 109°C. The reaction mixture was allowed to cool to room

temperature, and then triethylamine (0.6 mL) was added to neutralize the reaction mixture. The resulting mixture was allowed to stir at room temperature for an additional 30 minutes, transferred to a 500 mL round-bottomed flask, and concentrated under reduced pressure to give light yellow oily product (6.75 g). The crude product was shown to contain mainly two spots of TOC analysis (silica gel, 10% or 50% diethyl ether/hexanes). The crude material was purified by flash chromatography (silica gel, 20-40% diethyl ether/hexanes. The product thus collected (3.28 g, 45% yield) contained some amount of the starting diol, as shown by TLC analysis. This purified material was purified a second time by column chromatography (silica gel, 25-50% ethyl ether/hexanes). The desired product, 3,9-bis[(6-methylcyclohex-3-enyl)methoxy]-1,5,7,11-tetraoxaspiro[5.5]undecane (BMCHMO), was obtained as viscous light yellow oil in 20% yield. ¹H-NMR (CDCl₃, 300 MHz, mixture of diastereomers) δ 5.57 (m, 4H), 4.25-3.25 (m, 14H), 2.20-1.22 (m, 12H), 0.98-0.80 (m, 6H); ¹³C-NMR (CDCl₃, 300 MHz, mixture of diastereomers) δ 125.77, 125.74, 114.72, 114.68, 71.86, 69.28, 64.64, 64.37, 39.30, 32.78, 29.39, 27.70, 19.27; FTIR (neat) (cm⁻¹) 3022, 2956, 2896, 1654, 1459, 1432, 1374, 1342, 1251, 1210, 1175, 1106, 1048, 1009, 662. The ¹H-NMR Spectrum, the ¹³C-NMR Spectrum, and the FTIR Spectrum of 3,9-bis-[(6-methylcyclohex-3-enyl)methoxy]-1,5,7,11-tetraoxaspiro[5,5]undecane (BMCHMO) are shown in FIGS. 45-47, respectively. The desired BMCHMO-TOSU seemed to decompose on silica gel as indicated by FTIR spectral analysis which shows OH and C=O functionalities.

[0106] 3,9-Bis[(4-methyl-7-oxabicyclo[4.1.0]hept-3-yl)methoxy]-1,5,7,11-tetraoxaspiro[5.5]undecane (BMOCHMO) was prepared employing biphasic epoxidation due to the acid sensitive nature of this class of compounds. To a 100 mL round-bottomed flask was placed a mixture of 3,9-bis[(6-methylcyclohex-3-enyl)methoxy]-1,5,7,11-tetraoxaspiro[5.5]undecane

(impure sample containing decomposition product as indicated by FTIR spectrum which shows OH and C=O functionalities) (BMCHMO-TOSU 3, 1.45 g, 3.55 mmol) and 50 mL of methylene chloride (CH_2Cl_2). To this solution was added 0.5 M of an aqueous solution of sodium bicarbonate (25 mL, pH ~8). The resulting biphasic mixture was allowed to stir vigorously at room temperature, and then m-chloroperbenzoic acid (Aldrich, 77% max., mCPBA, 1.75, g, ~7.81 mmol) was slowly added in several portions over a period of 30 minutes. The resulting mixture was allowed to stir for an additional 5 hours at room temperature, and the reaction progress monitored by TLC (silica gel, 50% ether/hexanes). The two phases were separated, and the organic phase was diluted with methylene chloride (930 mL) and washed successively with 1 N aqueous NaOH (2x60 mL) and water (2x50 mL). The combined aqueous phase was back extracted with methylene chloride (2x100 mL). The organic phases were combined, dried over anhydrous Na_2SO_4 , filtered and concentrated under reduced pressure to give viscous yellow oil. The crude material was purified by flash chromatography (2% NEt_3 deactivated silica gel, 40-60% ethyl ether/hexanes). The desired product BMOCHMO-TOSU was obtained as light yellow oil in 27.6% yield. ^1H -NMR (CDCl_3 , 300 MHz, mixture of diastereomers) δ 4.08-3.98 (m, 4H), 3.90-3.80, (m, 4H), 3.48-3.04, (m, 10H), 2.16-1.20 (m, 12H), 0.87-0.76 (m, 6H), ^{13}C -NMR (CDCl_3 , 300 MHz, mixture of diastereomers) δ 114.70, 114.67, 71.44, 70.67, 69.36, 69.22, 65.69, 64.53, 64.47, 64.30, 64.23, 53.06, 52.55, 51.75, 51.52, 38.95, 35.86, 33.95, 32.93, 30.15, 28.89, 28.81, 27.67, 26.10, 18.94, 18.68, 15.13; FTIR (neat) (cm^{-1}) 2967, 2948, 2910, 1456, 1432, 1370, 1337, 1247, 1228, 1209, 1115, 1096, 1044, 1006, 911, 807, 731. The ^1H -NMR Spectrum, the ^{13}C -NMR Spectrum, and the FTIR Spectrum of 3,9-bis[(4-methyl-7-oxabicyclo[4.1.0]hept-3-yl)methoxy]-1,5,7,11-tetraoxaspiro[5.5]undecane (BMOCHMO) are shown in FIGS. 48-50, respectively.

[0107] From the foregoing, it will be seen that this invention is one that is well adapted to attain all the ends and objects herein above set forth together with other advantages which are obvious and inherent to the composition. It will be understood that certain features and subcombinations are of utility and may be employed without reference to other features and subcombinations. This is contemplated by and is within the scope of the claims. Since many possible embodiments may be made of the invention without departing from the scope thereof, it is to be understood that all matter herein set forth is to be interpreted as illustrative and not in a limiting sense.

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